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<p>(54) Title: PROCESS FOR THE PREPARATION OF CELLULOSIC FIBRE-REINFORCED THERMOPLASTIC COMPOSITE MATERIALS</p> <p>(57) Abstract</p> <p>A process for the preparation of a composite material containing a thermoplastic polymer and cellulosic fibres, having high tensile and flexural properties, reduced thermal expansion and high thermal stability (heat-deflection temperature), compared to the pure plastic is described. Cellulosic fibres are coated with electron beam-curable monomers, oligomers or mixtures thereof. The coated fibres are mixed with a powdered thermoplastic matrix material. The mixture is electron beam treated to a specified dose, to chemically cure the fibre coating by producing free radicals in the fibre, in the coating and in the matrix polymer. Free radical reactions form chemical bonds between the fibres and the synthetic matrix. Mechanical bonding, the result of a molecular entanglement, further improves the adhesion between the wood fibres and the thermoplastic polymer.</p>		

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**PROCESS FOR THE PREPARATION OF CELLULOSIC FIBRE-
REINFORCED THERMOPLASTIC COMPOSITE MATERIALS**

This invention relates to a process for the
5 preparation of a composite material containing a
thermoplastic polymer and cellulose fibres, having high
tensile and flexural properties, reduced thermal
expansion and high thermal stability, when compared to
pure plastics. More specifically, this invention
10 relates to a process for the preparation of a composite
material containing a thermoplastic polymer, cellulosic
fibres, and electron beam-curable coupling agents,
wherein the components of the composite material are
treated with electron beam radiation before or after
15 compounding to produce free radicals resulting in the
formation of chemical bonds between the fibres and the
synthetic matrix.

Background and Prior Art

Wood fibres and wood flour are currently used
20 industrially as filler materials for various
thermoplastics such as polypropylene, polyethylene, nylon
and polyesters to produce blends with high elastic
moduli, higher stiffness, reduced heat sensitivity and
lower overall production costs, including both material
25 and energy cost for processing. The adhesion between the
fibres and the matrix significantly affects many of the
properties of the composites. Chemical bonding between
the hydrophilic wood fibres and the hydrophobic polymer
cannot be achieved with standard mixing procedures.
30 Therefore, the produced composite has reduced tensile,
impact and flexural strength and increased moisture
absorption, as compared to the pure polymer.

Several methods have been suggested and studied
for improving the adhesion between wood fibres and
35 thermoplastic matrices.

The fibres can be coated with mixtures of
monomers, such as styrene and chemical initiators, such
as benzoyl peroxide. The coating is polymerized and

bonding occurs during mixing at an elevated temperature, or during extrusion. Molecules of the polymerized coating become intertwined with the polymer molecules, during processing, producing a mechanical bond.

5 U.S. Patent 4,464,510 discloses a method of producing a composite system consisting of thermoplastics and a natural fibre bonded with an unsaturated polyester resin without the addition of an initiator. As an optional step, this patent teaches that chemical
10 initiators or radiation can be used. When radiation is used, it is disclosed that the wood fibres are pretreated with ionizing radiation before admixing with the unsaturated polyester resin. The present invention is a significant improvement over this prior art patent in
15 specifying more efficient chemically reactive coupling agents and in elaborating a more technically feasible method for radiation processing. Specifically, in the process of the present invention, irradiation occurs after the fibres have been coated with an electron beam-
20 curable coupling agent and mixed with the thermoplastic polymer. The wood fibre-filled thermoplastic polymers thus produced have improved mechanical properties over the prior art products.

U.S. Patent 3,645,939 describes mixing
25 ethylenically unsaturated carboxylic acid or anhydride coupling agent, thermoplastic materials containing labile atoms, a hydroxy group containing material, such as cellulose, and treating with a free radical generating catalyst, including ionizing radiation. Such a system
30 forms a bridge between the matrix and the hydroxy group containing material.

U.S. Patent 4,380,522 discloses a process for the manufacture of shaped articles from polyolefine compositions, modified by means of polar monomers, and
35 cellulosic fibres. The polar monomers of this reference

include unsaturated monocarboxylic acids such as acrylic, methacrylic or chloroacrylic acid, or unsaturated polycarboxylic acids such as maleic, fumaric and itaconic acid, or the anhydrides derived from these acids, such as maleic anhydride. The polyolefine and polar monomers are graft polymerized by either irradiation or in the presence of initiators. The modified polyolefine or unmodified polyolefine and polar monomers are mixed with the cellulose and subjected to a malaxating operation at high temperature.

Each of the suggested methods for improving the adhesion between wood fibres and thermoplastic matrices, has seen limited success and industrial acceptance. Select coupling agents have been shown to improve the mechanical properties of some specific matrix/fibre composites but the agents cannot be used universally. The ability of a specific chemical to couple a polymer and a fibre, depends on the polymer type, the wood species and the wood composition (bleached or unbleached). Coupling agents must be tailored to each specific wood fibre - reinforced composite, often making their industrial use impractical.

Coating the wood fibres with a polymer, such as polystyrene, prior to compounding, provides a surface for the matrix to bond through molecular entanglement, but does not provide a chemical bond between the coating and the fibre. Initiating polymerization of the coating by introducing chemicals such as benzyl peroxide, along with mixing/compounding at elevated temperatures, may also cause the fibres to clump together, lowering the final mechanical properties of the composite because of poor fibre dispersion.

Irradiating wood fibres in air produces peroxides and hydroperoxides on the surface of the fibres. Their concentration and distribution on the surface depends on

the wood species, the wood composition (bleached or unbleached), the dose, the dose rate, the temperature during irradiation and the availability of oxygen to the fibres. The number of these active peroxide sites
5 available to initiate polymerization of a coating, may also be a function of the time between the fibre irradiation and the application of the coating. Such complexities make the optimization of this method and the production of a consistent product difficult.

10 The use of ethylenically unsaturated carboxylic acid or anhydride along with a free radical catalyst can only be used with hydroxy group containing materials, producing weak hydrogen bonds between the matrix and the fibres and limiting the reinforcing benefits.

15 Therefore there is a need for a process to produce fibre-reinforced plastic composites with good mechanical and thermal properties which overcome the disadvantages of the prior art processes. The thermoplastic composite material of the present invention, contain chemical bonds
20 between the fibre/coupling agent interface and the coupling agent/thermoplastic polymer.

Summary of the Invention

The process of the present invention is based on
25 the recognition that a fibre-reinforced plastic composite with good mechanical and thermal properties can be formed if a chemical bond between the plastic matrix and the fibre's natural polymer is ensured by using EB-curable unsaturated oligomers, vinyl monomers, acrylate
30 monomers, or there mixtures as coupling agents and treating the components of the composite with an electron beam after mixing the treated fibre with the thermoplastic material. Upon electron beam treatment, these reactive additives can form an adhesion-mediated
35 layer of the fibre matrix interface.

In the process of the present invention, the wood fibres are coated with an electron beam (EB)-curable monomer/oligomer mixture. The coated fibres are then mixed with a powdered thermoplastic matrix material. The mixture is EB treated to a specific dose prior to or after extrusion or other similar procedures resulting in intimate melt-mixing, to chemically cure the fibre coating by producing free radicals on the fibre surfaces, in the coating and in the matrix polymer. Free radical reactions during further compounding and extrusion will form chemical bonds at both the coating/fibre interface and the matrix/coating interface. Mechanical bonding, the result of a molecular entanglement at the matrix/coating interface further improves the adhesion between the wood fibres and the thermoplastic polymer.

In one embodiment of the present invention there is provided a process for the preparation of a thermoplastic material containing thermoplastic polymer, cellulose fibre and EB-curable coupling agents comprising the steps of: treating the fibres 10 to 50% by weight of the total composite, with a coupling agent mixture in an amount of 1 to 10% by weight, related to the fibre; mixing the treated fibres with a thermoplastic powder, 45 to 90% by weight of the total composite and electron beam treating the mixture to a dose of 5 to 50 kGy to produce free radicals; and compounding the cured mixture to form chemical bonds at the fibre-resin interface and the resin-polymer interface.

30 Detailed Description

In preparing the thermoplastic composite materials of the present invention, 45 to 90% by weight, preferably 55 to 75% by weight, of the thermoplastic polymer and 10 to 50% by weight, preferably 20 to 35% by weight, of a cellulosic fibre are used. The fibres are

treated with an EB-curable coupling agent consisting of unsaturated polyesters and/or vinyl monomers and/or acrylated monomers/oligomers in an amount of 1 to 10% by weight, preferably 1.5 to 7% by weight, related to the fibre mass. The fibres are mixed with thermoplastic powder (melt flow index greater than or equal to 5 gram/10 minutes) and the mixture is electron beam treated to a dose of 5 to 50 kGy, preferably 6 to 16 kGy, prior to standard thermoplastic processing such as extrusion, injection moulding, calendering or thermoforming.

Examples of cellulosic material which can be used in the present process include seed fibres such as cotton, woody fibres such as coniferous and deciduous woods, bast fibres represented by flax, leaf fibres such as sisal, and fruit fibres such as coconut. However, wood fibres are preferred.

Various thermoplastic materials can be used in the present invention. For example, materials such as polypropylene, polyethylene, and polyvinyl chloride. These polymers are preferred, however, other thermoplastics such as copolymers of olefines, styrenes, acrylics, as well as polycarbonates, polyamides and polyesters could also be used in the present invention.

The properties of wood fibre-filled polyester polymers can be significantly improved if the adhesion between the hydrophillic fibres and the hydrophobic matrix could be increased. In the electron beam process of the present invention, the fibres are coated with an electron beam-curable monomer/oligomer mixture. This mixture includes for example unsaturated oligomers, vinyl monomers, acrylated monomers or mixtures thereof. More specifically, the coupling agents of the present invention are preferably epoxy acrylates, polyester-urethane acrylates and polyether acrylates or mixtures thereof. A specific example of coupling agents includes

a mixture of hexanediol diacrylate, long-chain acrylated diol, tripropylene glycol diacrylate, vinyl ester resin and isodecyl acrylate.

Chemical bonds are easily produced at both the
5 matrix/coating interface and the coating/fibre interface, using the process of the present invention. The amount of bonding is a function of the applied dose, which is easily controlled. This chemical bonding improves the mechanical properties of thermoplastics containing wood
10 fibres. In the present invention, the mixture is electron beam treated to a dose of 5 to 50 kGy, more preferably 6 to 16 kGy.

In addition to the components discussed above other product additives such as antioxidants and fibre
15 dispersion aids can be added, provided that the physical properties of the resulting product are not adversely affected.

The following examples illustrate the best modes contemplated for carrying out this invention, but are not
20 to be construed as limiting.

Example 1

Wood fibres were coated with 5%, related to the fibre mass, of a mixture comprising hexanediol diacrylate
25 (30%), long chain acrylated diol (20%), tripropylene glycol diacrylate (20%), vinyl ester resin (20%) and isodecyl acrylate (10%) and a mixture of 25% fibres and 75% (by weight) polypropylene was prepared. The mixture was electron beam treated at a dose of 10 kGy. The
30 resulting mixture was then further processed by mixing using a low shear Henschel blender, extrusion and injection moulding.

The resulting material was then subjected to a number of tests of the American Society for Testing and
35 Materials (ASTM) to determine for example, flexural

modulus, flexural strength, tensile modulus, tensile strength, impact strength, and the coefficient of thermal expansion. These tests are standard tests known in the art. The properties of this material (20% WF, 10 kGy) were compared to: unmodified polypropylene material (PP); a commercially available product of polypropylene (Himont PP) and a composite as described above which was not electron beam cured (20% WF, 0 kGy). These results are found in Table 1.

Example 2

Thirty-five percent wood fibres were coated with the coupling agents as described in Example 1. The coated fibres were mixed with 63% polypropylene. The mixture was electron beam treated at a dose of 10 kGy. The resulting mixture was then further processed as described in Example 1. The resulting composite material was subjected to the tests referred to in Example 1. The results from these tests are found in Table 1 (35% WF, 10 kGy and 35% WF, 0 kGy).

The last column in Table 1 shows the percent change using 35% wood fibre between the unirradiated and irradiated composite material. It will be readily noted that the flexural modulus, and flexural strength increased in the irradiated composite material as compared to the unirradiated composite material. There was no change in the tensile modulus property between the unirradiated and the irradiated samples. However, the tensile strength and impact strength increased in the materials irradiated as compared to the unirradiated materials. The coefficient of thermal expansion decreased in the irradiated sample.

The results from these tests clearly show that the chemical bonding produced in the present invention improves the mechanical properties of thermoplastics

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containing wood fibres.

Table 1

Wood Fibre Polypropylene Composite Physical Properties

Property	PP	Himont- PP	20% WF 0 kGy	20% WF 10 kGy	35% WF 0 kGy	35% WF 10 kGy	35% WF Irradiated vs Unirradiated % change
Flexural Modulus, GPa	1.41	1.7	2.17	2.25	3.04	3.46	13.98
Std. dev.	0.03		0.03	0.08	0.04	0.03	
Flexural Strength, MPa	37.81		39.11	46.38	44.01	62.47	41.95
Std. Dev.	0.21		0.12	0.89	0.25	0.79	
Tensile Modulus, GPa	1.87		3.00	2.76	3.93	3.89	-1.17
Std. Dev.	0.07		0.16	0.14	0.18	0.10	
Tensile Strength, MPa	37.26	34.	33.11	35.12	35.29	48.80	38.29
Std. Dev.	0.53		0.88	0.73	1.35	0.78	
Impact Strength, Izod, unnotched, J/m	675.		131.	92.	87.	101.	16.86
Std. Dev.	28.		8.	7.	11.	11.	
Coefficient of Thermal Expansion. °C ⁻¹ (x10 ⁶)	134.3		48.3	45.1	22.4	18.1	-19.20

Example 3

Thirty-five percent wood fibres were mixed with
5 1.75% of a coupling agent consisting of:
16.6% aliphatic polyester-urethane-acrylate,
15.0% aromatic polyester-urethane-acrylate,
1.7% epoxidized soya oil acrylate,
3.0% poly(propylene glycol) diacrylate,
10 3.3% neopentyl glycol diacrylate,
24.0% hexane diol diacrylate, and
33.4% tri(propylene glycol) diacrylate.

and mixed with 52% of polypropylene homopolymer, having a
Melt Flow Index (MFI) of 10g/10 min, and with 13% of and
15 ethylene-propylene copolymer.

The dry blend was first mixed in a high-speed fluid
mixer and then extruded using a twin-screw extruder and
pelletized. The above described pellets were treated
with electron from an electron accelerator having a 10
20 MeV beam energy, to an absorbed dose of 10 kGy. The EB-
treated pellets were re-pelletized on the same twin-screw
extruder 76 hours after being irradiated. Table 2 shows
the main properties, determined as described in Example
1, of the EB-treated composite made according to the
25 present invention as compared to the unirradiated mixture
having the same polymer and fibre composition.

Table 2
Properties of Wood Fibre Reinforced Plastics
Modified with Co-Polymers and EB-Treatment

5

Property	Composition ¹		
	PP+EP	PP+EP (65%) +WF (35%)	PP+EP (65%) +WF (35%)+EB
Flexural Strength, MPa	34.6	32.3	39.6
Flexural Modulus, GPa	1.88	3.39	3.75
Impact Strength, J/m (Unnotched)	>250	64.7	67.7

¹PP: Polypropylene; EP: Ethylene/propylene copolymer; WF: Wood fibres; EB: Electron beam treatment.

It is understood that the invention has been disclosed herein in connection with certain examples and embodiments. However, such changes, modifications or equivalents as can be used by those skilled in the art are intended to be included. Accordingly, the disclosure is to be construed as exemplary, rather than limiting, and such changes within the principles of the invention as are obvious to one skilled in the art are intended to be included within the scope of the claims.

Claims

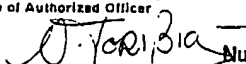
1. A process for the production of a thermoplastic composite material containing thermoplastic polymer, cellulosic fibres and coupling agents, comprising the steps of:
 - (a) treating the fibres with EB-curable coupling agents, wherein the coupling agent is selected from the group consisting of unsaturated oligomers, vinyl monomers, acrylated monomers, and mixtures thereof;
 - (b) mixing the treated fibres with thermoplastic polymer material.
 - (c) electron beam treating the mixture to initiate the chemical curing of the coupling agents by producing free radicals; and
 - (d) compounding the EB-treated mixture to form chemical bonds at the fibre-resin interface and the resin-polymer interface.
2. The process of claim 1 wherein 10-50% by weight of the cellulosic fibres are treated with EB-curable coupling agents in an amount of 1 to 10% by weight, relative to the fibres and the treated fibres are mixed with 45 to 90% by weight, of the thermoplastic polymer.
3. The process of Claim 2 wherein the mixture is electron-beam treated to a dose of 5 to 50 kGy.
4. The process of Claim 2 wherein the 20 to 35% by weight, of the cellulosic fibres are treated with EB-curable agents in an amount of 1.5 to 7% by weight, relative to the fibres and the treated fibres are mixed with 55 to 75% by weight, of the thermoplastic polymer.

5. The process of Claim 4 wherein the mixture is electron-beam treated to a dose of 6 to 16 kGy.
6. The process of Claim 1 wherein the coupling agent is selected from the group consisting of epoxy acrylates, polyester-urethane-acrylates and polyether acrylates or mixtures thereof.
7. The process of Claim 4 wherein the coupling agent is a mixture of hexanediol diacrylate, long chain acrylated diol, tripropylene glycol diacrylate, vinyl ester resin and isodecyl acrylate.
8. The process of Claim 1 wherein the thermoplastic polymer is selected from the group consisting of polypropylene, polyethylene, polyvinylchloride, copolymers of olefines, styrenics, acrylics, polyamides, polyesters and polycarbonates.
9. The process of claim 8 wherein the thermoplastic polymer is selected from the group consisting of polypropylene, polyethylene and polyvinylchloride.
10. The process of Claim 1 wherein the thermoplastic powder has a melt flow index greater than 5 grams per 10 minutes.
11. The process of Claim 1 wherein the compounding, of the cured mixture, is selected from the group consisting of extrusion, injection moulding, calendering and thermoforming.
12. The process of claim 1 wherein the cellulosic fibres are wood fibres.

13. The process of claim 11 wherein the thermoplastic composite material is electron beam treated after compounding the mixture.

14. The process of claim 1 wherein the production of a thermoplastic composite material containing thermoplastic polymer, wood fibres and EB-curable coupling agents, comprises the steps of:

- (a) treating the wood fibres, 20-35% by weight of the total composite, with EB-curable coupling agents comprising a mixture of hexanediol diacrylate, long chain acrylated diol, tripropylene glycol diacrylate, vinyl ester resin and isodecyl acrylate; in an amount of 1.5 to 7% by weight, relative to the fibres;
- b) mixing the treated fibres with thermoplastic polymer powder, 55 - 75% by weight of the total composite material;
- (c) electron beam treating the mixture to a dose of 6-16 kGy, to cure the coupling agents and to produce free radicals; and compounding the cured mixture to form chemical bonds at the fibre-resin interface and the resin polymer interface.

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, in all) ⁶		
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A	US, A, 4464510 (CZVIKOVSKY ET AL) 7 August 1984, see the whole document --	1-14
A	CA, A, 1269187 (BESHAY, ALPHONS D) 15 May 1990, see the whole document -- -----	1-14
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